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Analysis of five Gigantic Jets observed near Réunion Island with video and photographic cameras

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ABSTRACT: Five gigantic jets (GJ) have been recorded by a camera on March 7th 2010, at a very close distance above an isolated tropical storm east of Réunion Island. Three of them were produced within about 4 minutes before the storm reached its coldest cloud top temperature (-81°C), and two others occurred during the extension of the cloud. The GJs tops have been estimated between 80 and 90 km. According to ELF data recorded at Nagycenk (Hungary), all GJs are negative. The GJs are accompanied by long continuous cloud illumination and they are preceded and followed by intermittent optical flashes from the cloud. The jet duration ranged from 333 ms to 850 ms while that of the leading jets markedly varied from 33 to 167 ms and that of the trailing jets ranged from 300 to 683 ms. The trailing jet exhibits a continuous decrease of luminosity in different parts of the jet (lower channel, transition zone and for most events carrot sprite-like top) and in the cloud. The lowers channels (~20-40 km altitude) produce blue luminosity which decreases with altitude and becomes more and more diffuse with time. The transition zone (around 40-65 km) consists of red luminous beads slowly going up (~ 10^4 m s^{-1}), retracing the initial leading jet channels.

1. INTRODUCTION

Gigantic jets (GJ) are electrical discharges shooting up from a thundercloud [Pasko et al., 2002, Su et al., 2003] which can reach terminal altitudes within the lower ionosphere (70-90 km). In a storm with a normal charge structure, the theory predicts negative polarity for the GJ, i.e. carrying negative charge upwards [Krehbiel et al., 2008]. This theory explains the propagation of the GJ out of the cloud after the discharge starts as an intracloud (IC) process between the unbalanced main charge regions. The upward propagating leading jet can be considered to have a role in the GJ process equivalent to that of the stepped leader in the cloud-to-ground (CG) lightning flash. The trailing jet is characterized by a bright top region which forms the "transition region" [van der Velde et al., 2007] rising with a speed from about 100 km s^{-1} to a few km s^{-1} as it approaches its maximum altitude.

We report here on five GJs recently detected by video and photo cameras above a storm close to the east coast of Réunion Island in the Indian Ocean. Thanks to the proximity of the observation (about 50 km), the GJ events were recorded in unprecedented detail and luminosity from the cloud and from different parts of the jet discharge, including very weakly luminous ones, could be analyzed.

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2. DATA AND METHODOLOGY

The videos recorded from a CCD Sony camera KPC-350 BH provide series of images which have been de-interlaced in frames separated by 16.7 ms. Color photographs were taken with a highly sensitive NIKON D200 equipped with an 18 mm f/3,5 AF-S NIKKOR aspheric lens and used at exposure time of 20 s. Data from the geostationary Meteosat-7 satellite located at a longitude of 58°E provide the cloud top temperatures every 30 minutes. The parallax error (about +0.0675° in latitude) for cloud top location is taken into account. Data from the Very Low Frequency (VLF) global ground based World Wide Lightning Location Network (WWLLN) provide cloud-to-ground (CG) lightning flashes with low detection efficiency. The video imagery provides also information about lightning activity, especially in terms of optical flashes.

The timing of the GJ video images is precisely determined thanks to a statistical method based on the time intervals with the events detected by the WWLLN synchronized to the Global Positioning System (GPS). The correct timing of the jets allows us associating ELF signals recorded at the Széchenyi Isván Geophysical Observatory near Nagycenk, Hungary. Time series of the vertical electric field provide the polarity of the jets.

3. RESULTS

*3.1. **Conditions for production of the GJs***

The camera recorded five GJs at 17h 40min 24s (GJ1), 17h 42min 49s (GJ2), 17h 44min 5s (GJ3), 18h 26min 6s (GJ4), and 18 h 29min 20s (GJ5) UT, on 7 March 2010, east of Réunion Island. Figure 1 displays cloud-top temperature images from Meteosat 7 in the area of the storm at 1738 and 1838 UT, and the locations of CG lightning strokes detected by the WWLLN. The western part of the cloud to be the most electrically active. The superimposed lines of sight to the GJs clearly correspond to the strongest cloud development and the main location of the strokes, especially in Fig. 1b. Before 1800 UT the flash rate is from 1 to 2 min^{-1} with a maximum of 1.8 min^{-1} at 1730 UT, just before the first GJs recorded by camera. The first GJs occur within a very short period (~ 4 min) probably before the storm reaches its complete vertical development and when the average flash rate is low (~ 1 min^{-1}). During an interval of 335 s (17h 38min 30s – 17h 44min 5s) preceding the third jet, only one stroke has been detected by the WWLLN. The rates of lightning strokes and lightning flashes fluctuate markedly after 1800 UT. The main stroke area (Figure 1b) slightly expands and shifts to the west while stroke density increases markedly. Two additional GJs are produced during a relatively low flash rate (1.2 min^{-1}). For these GJs the periods without flash detected by the WWLLN last 136 s and 121 s, respectively.

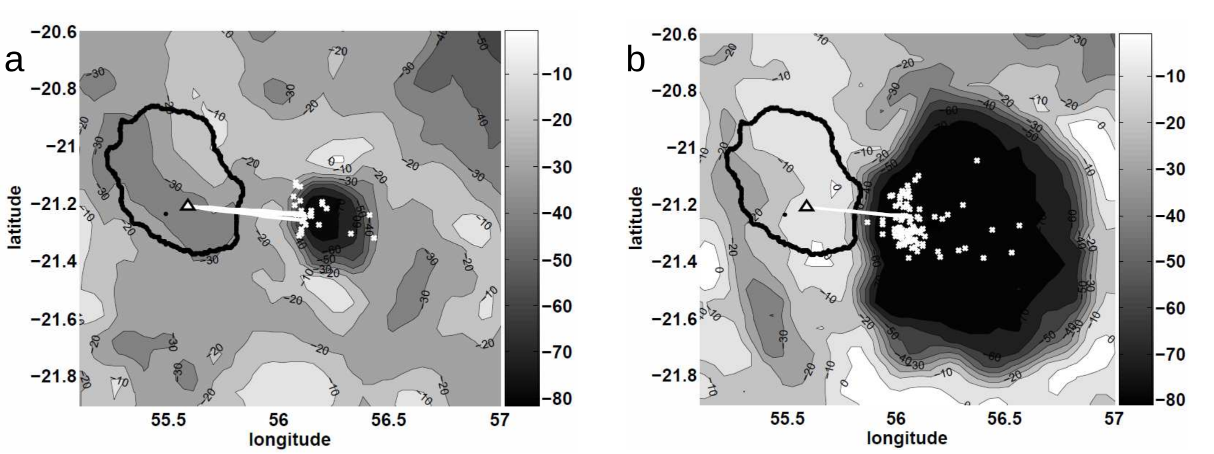

Figure 1. Charts of the cloud top temperature in the area of the GJ-producing storm: (a) 1738 UT and (b) 1838 UT. The lightning strokes detected by the WWLLN over a 20 minute-period centred at the scanning time are indicated with white crosses The triangle in Réunion Island indicates the video camera observation station and

the lines from that location indicate the GJ lines of sight ((a) for GJ1, GJ2, and GJ3, (b) for GJ4 and GJ5).

3.2. *Characteristics of the GJs*

Figure 2 provides an overview of the durations of the main phases of the GJs (leading jet, trailing jet) and of the associated cloud luminosity. These durations are estimated from the analysis of the video observations. The duration of the entire cloud discharges recorded in the video imagery ranges from 1 s to 1.40 s whereas the duration of the jets ranges from 0.33 s to 0.85 s. In all five events, the GJ is preceded by permanent cloud luminosity with intermittent pulses of light of which the duration is of the order of half a second (300 to 668 ms). The cloud remains luminous during and after the visible part of the GJs, indicating continuous charge transfer.

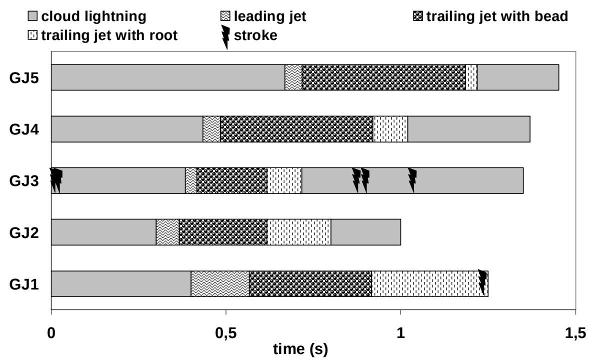

Figure 2. Comparison of the durations of the various luminous phases of each GJ event. The flash symbols indicate occurrences of strokes detected by the WWLLN.

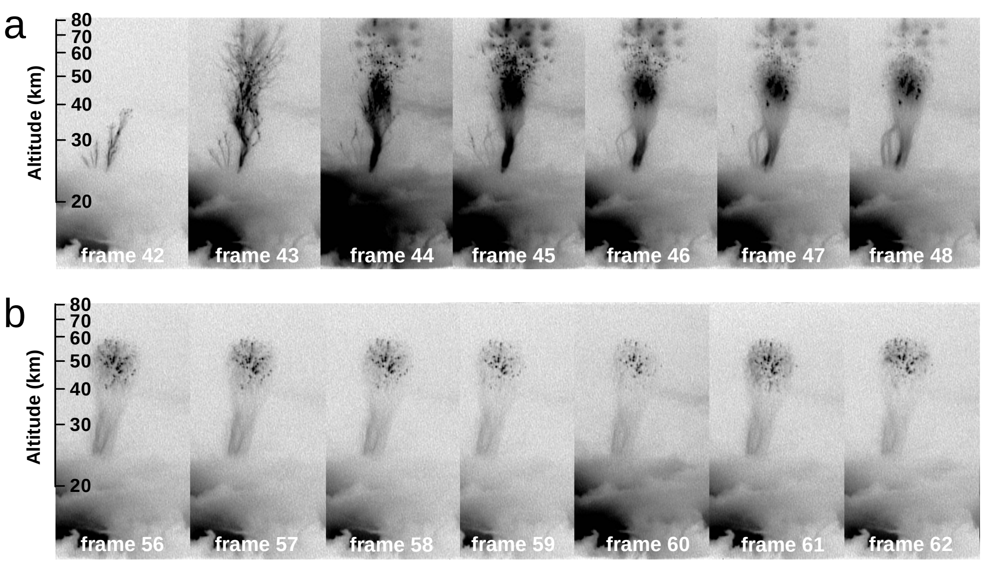

Figure 3. Series of seven successive de-interlaced frames in inverted color from the video imagery of GJ5. t = 0 (frame 1) corresponds to the initial luminosity from the event. (a) t = 684.7 to 801.6 ms: leading jet / beginning of the trailing jet with beads. (b) t = 918.5 to 1035.4 ms: trailing jet with rebrightening (frames 60 and 61).

3.3. *Analysis of one case of GJ*

The leading jet is the most variable phase in term of duration, from 33 ms to 167 ms (i.e. average velocity from 0.4×10^6 m s^{-1} to 2.0×10^6 m s^{-1}) as seen in Figure 2. It always starts with several channels emerging from the cloud top and ends with a well branched structure and a relatively low brightness. Figure 3 shows two series of seven frames from the video of GJ5. The leading jet has a short duration (50 ms). When the GJ is fully developed, (frame 43), its brightness and that of the cloud increase simultaneously (analogous to a "return stroke" in CG flashes). During several frames, a structure with carrot sprite-like patches of light and/or a multitude of beads remains near the top. Some leader channels, initially developed during the leading jet become rapidly attached to the trunk of the jet (frames 45-46). During the trailing jet, the brightness simultaneously decreases in the most luminous parts of the jet (the main channel below 30 km, the transition region around 50 km, the diffuse top) and in the cloud. The transition region which disappears before the lower channel, consists of luminous beads slowly rising (~ 10^4 m s^{-1}) along leading jet channels, superimposed on a glow. During the trailing jet of GJ5 an increased brightness in the cloud (frame 60) precedes an increased brightness of the beads and bursts of new streamers just below the beads in the transition region (frame 61).

4. DISCUSSION AND CONCLUSIONS

ELF data recorded at NCK show all GJs are of negative polarity, as most cases analyzed in the literature [Su et al., 2003, Krehbiel et al., 2008]. Three GJs are produced before the end of the vertical development of the storm and two during its horizontal expansion, all with a low CG lightning flash rate. The long and intermittent in-cloud luminosity preceding the GJs in the video imagery is consistent with IC discharges which can create the conditions of upwards propagation, by neutralizing charge within the cloud. The theory about the GJ upward development based on the unbalanced charges due to the mixing of positive cloud charge and negative screening charge at the cloud top [Krehbiel et al., 2008] can explain the production of the two last GJs. Furthermore the development of the anvil can be efficient for the depleting of the upper positive cloud charge. For the three first GJs, another explanation is possible because the screening charge layer above cloud could have not been developed at the beginning of the storm. The mid level negative charge can be larger than the positive charge above if it is produced by the non inductive charging process at two levels : at lower level (warmer temperature) the ice crystals are negative and they go up and at higher level (lower temperature) the graupel pellets are negative and they go down.

Our observations clearly show the upward velocity is not constant during the jet propagation. The leading jet starts with several visible channels above the cloud, some of them rising and markedly accelerating above about 50 km to reach velocities of the order of 10^6 - 10^7 m s^{-1}. When the fully developed stage is reached, the jet and the cloud exhibit a luminosity increase with variable intensity for all events. This increase of light has a strong analogy with the “return stroke” in CG flashes. During the trailing jet the luminosity continuously decreases in the cloud and in two distinct regions of the jet: the blue lower main channel (around 20-40 km altitude) of which the luminosity decreases with altitude, and the transition zone (around 40-65 km) with red luminous beads rising at low velocity (~ 10^4 m s^{-1}) and retracing original leading jet channels, initially superposed on a bright glow with unresolved details, and in a later stage, groups of streamers occurring just under the level of the bright beads. A weak re-illumination can occur within the cloud and in the trailing jet regions. The trailing phase of the jet exhibits an analogy with the continuing current generally observed after the return-stroke of a positive CG flash, with possible superimposed M-components.

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